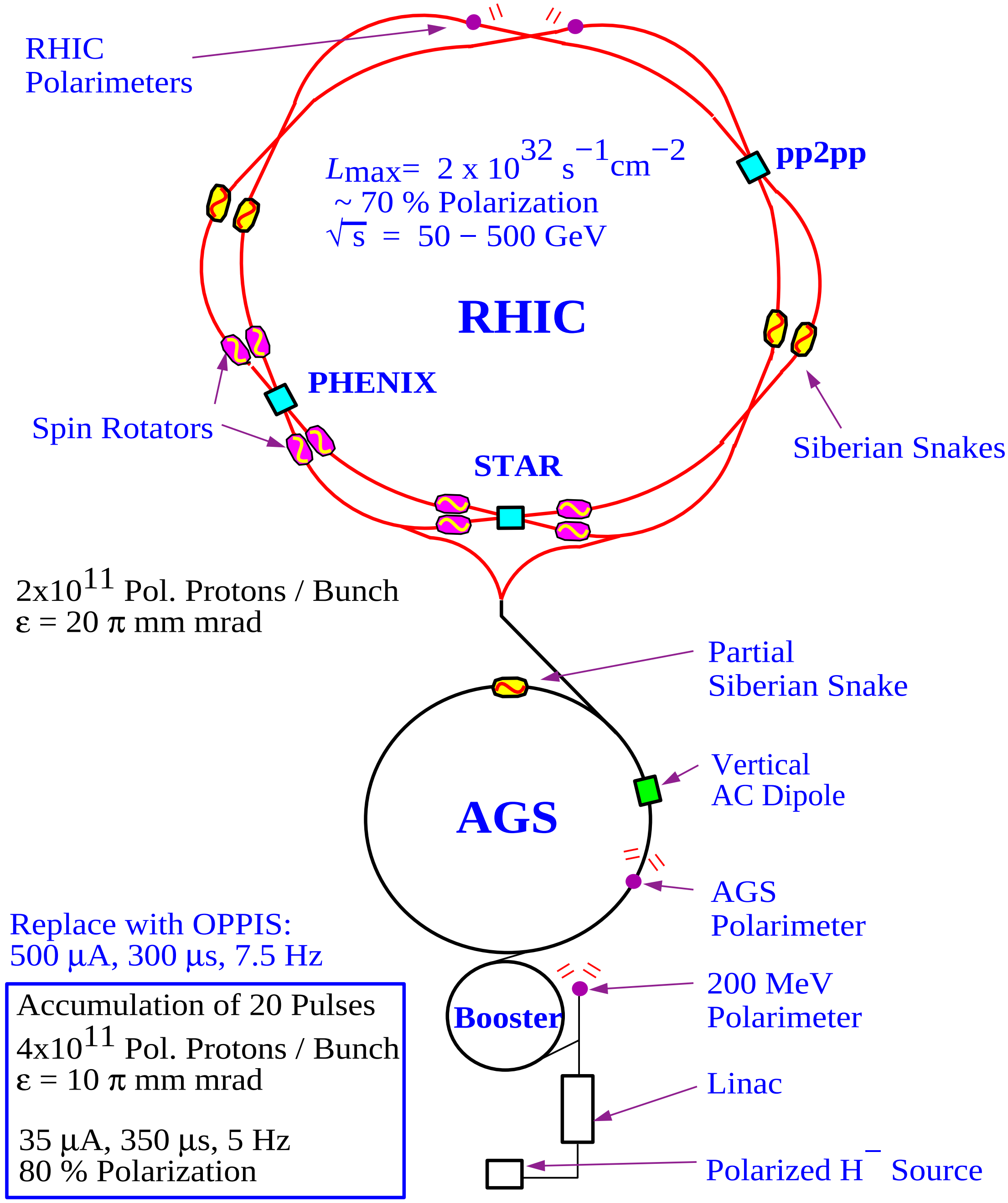
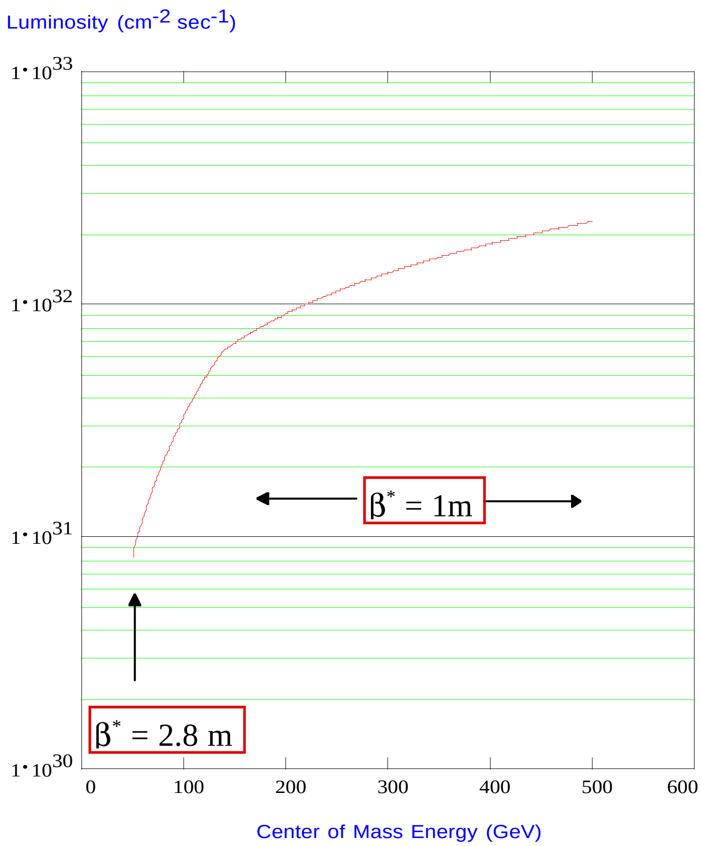
Polarized Proton Collisions at BNL

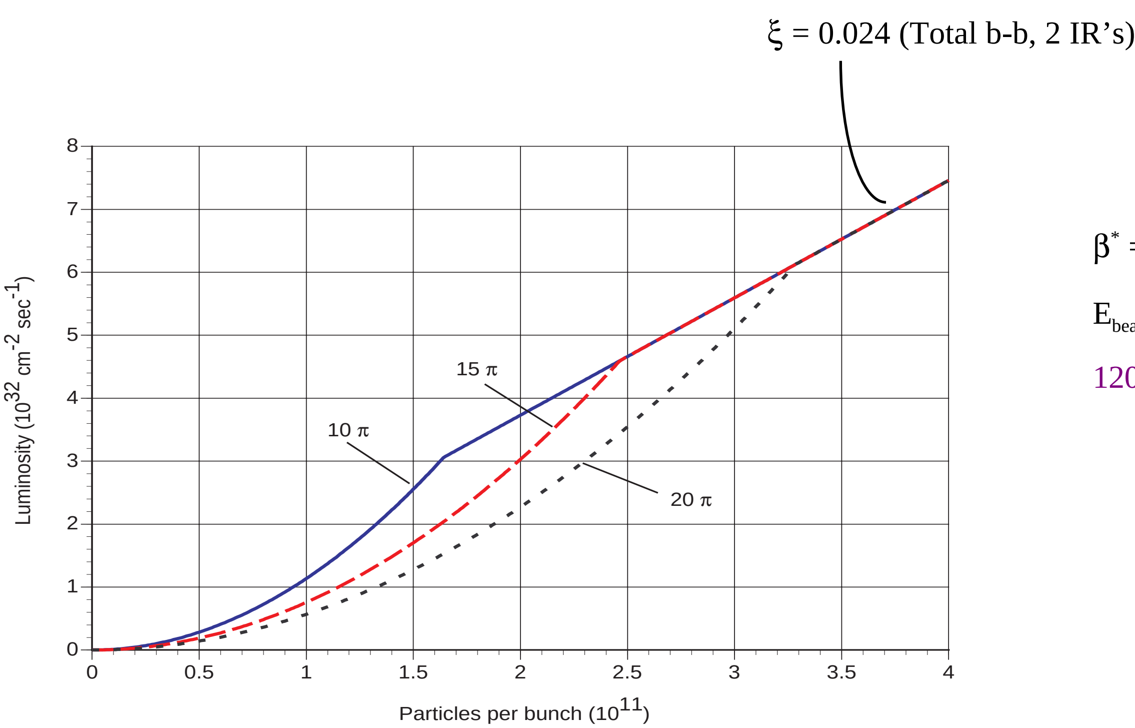




2×10^{11} p / bunch

$\varepsilon_N(95\%) = 20\ \pi$ mm-mr

120 bunches / ring



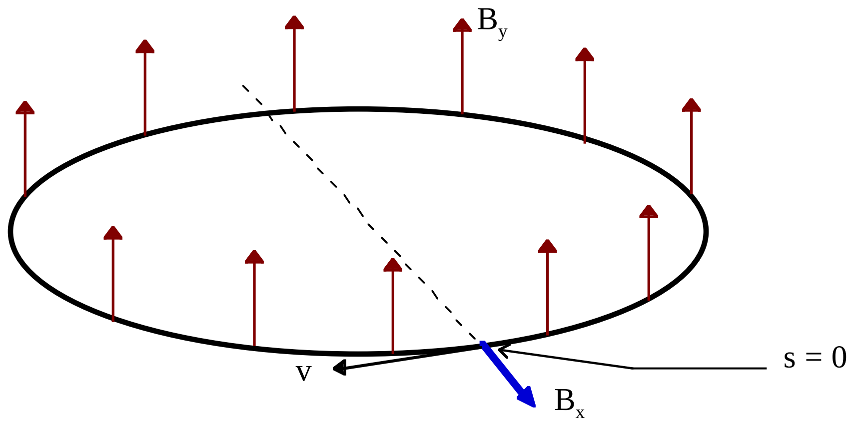
$\beta^* = 1$ m

$E_{beam} = 250$ GeV

120 bunches / ring

Crossing Imperfection Resonances...

Single horizontal field error producing a spin rotation about the x-axis of amount $\Delta\phi = 2\pi\varepsilon = G\gamma\, B_x\, L/(B\rho)$ ...



Once around the accelerator, the spin is governed by

$$\begin{pmatrix} S_x \\ S_y \\ S_z \end{pmatrix}_{n+1} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos 2\pi\varepsilon & -\sin 2\pi\varepsilon \\ 0 & \sin 2\pi\varepsilon & \cos 2\pi\varepsilon \end{pmatrix} \begin{pmatrix} \cos 2\pi G\gamma & 0 & \sin 2\pi G\gamma \\ 0 & 1 & 0 \\ -\sin 2\pi G\gamma & 0 & \cos 2\pi G\gamma \end{pmatrix} \begin{pmatrix} S_x \\ S_y \\ S_z \end{pmatrix}_n$$

$$= \begin{pmatrix} \cos 2\pi G\gamma & 0 & \sin 2\pi G\gamma \\ \sin 2\pi\varepsilon \sin 2\pi G\gamma & \cos 2\pi\varepsilon & -\sin 2\pi\varepsilon \cos 2\pi G\gamma \\ -\cos 2\pi\varepsilon \sin 2\pi G\gamma & \sin 2\pi\varepsilon & \cos 2\pi\varepsilon \cos 2\pi G\gamma \end{pmatrix} \begin{pmatrix} S_x \\ S_y \\ S_z \end{pmatrix}_n$$

Spin rotation axis
(stable spin direction):

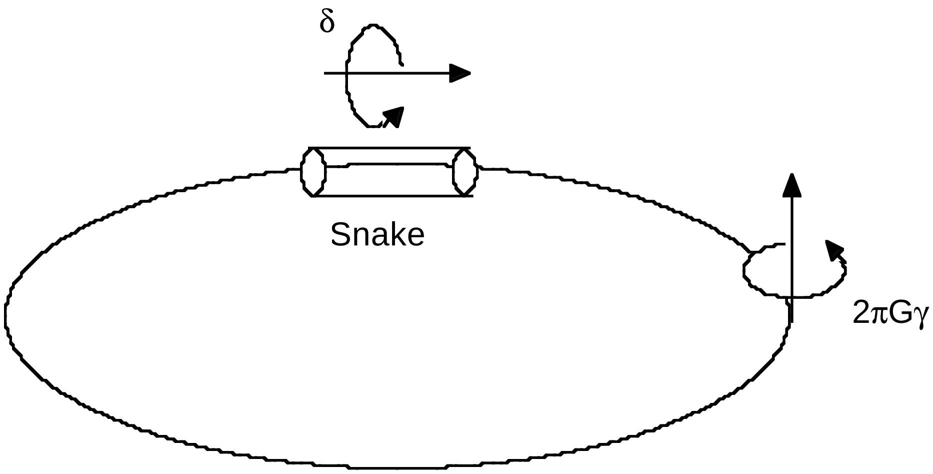
$$n_x = -\frac{\sin\pi\varepsilon\cos\pi G\gamma}{\sqrt{\sin^2\pi\varepsilon + \cos^2\pi\varepsilon\sin^2\pi G\gamma}},$$
$$n_y = -\frac{\cos\pi\varepsilon\sin\pi G\gamma}{\sqrt{\sin^2\pi\varepsilon + \cos^2\pi\varepsilon\sin^2\pi G\gamma}},$$
$$n_z = -\frac{\sin\pi\varepsilon\sin\pi G\gamma}{\sqrt{\sin^2\pi\varepsilon + \cos^2\pi\varepsilon\sin^2\pi G\gamma}}.$$

If $\varepsilon = 0$, $\quad$ ***n*** = (0, ±1, 0)
If $G\gamma$ = *intgr*, $\quad$ ***n*** = (±1, 0, 0).

Resulting precession angle, $2\pi\nu_s$, (ν_s= "spin tune") given by:

$$\cos\pi\nu_s = \cos\pi\varepsilon\,\cos\pi G\gamma$$

Siberian Snakes and Partial Siberian Snakes...



Intentionally introduce a strong horizontal field to produce large spin rotation --

$$\begin{pmatrix} S_x \\ S_y \\ S_z \end{pmatrix}_{n+1} = \begin{pmatrix} \cos\delta & \sin\delta & 0 \\ -\sin\delta & \cos\delta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos 2\pi G\gamma & 0 & \sin 2\pi G\gamma \\ 0 & 1 & 0 \\ -\sin 2\pi G\gamma & 0 & \cos 2\pi G\gamma \end{pmatrix} \begin{pmatrix} S_x \\ S_y \\ S_z \end{pmatrix}_n = M \begin{pmatrix} S_x \\ S_y \\ S_z \end{pmatrix}_n$$

$$\cos\pi\nu_s = \cos(\delta/2)\cos\pi G\gamma$$

So, if $\delta = \pi$ (Full Siberian Snake), then $\nu_s = 1/2$,

if $\delta = 0$ (No Snake!), then $\nu_s = G\gamma$,

and otherwise (Partial Snake), then

ν_s cannot be an integer!

RHIC Requirements for Polarized Proton Operation

- 25 GeV ----> 250 GeV
- Longitudinal polarization at major experiments
- Full Siberian Snake(s)

  $\Rightarrow$ (1.8)(250 - 25) = 405 imperfection resonances, plus many intrinsic resonances

- Need fine vertical orbit control / correction

  $\Rightarrow$ investigating harmonic and other correction schemes

Project Funding --

Primarily from The Institute for Chemical and Physical Research (RIKEN), Japan

- Funding for Accelerator Components: 1B Yen ($10 M)

  (Less, due to exchange rate!)

  constant issue... (today: **145** Y/$)

Superconducting Magnet System Requirements

For the Siberian Snakes and Spin Rotators in RHIC:

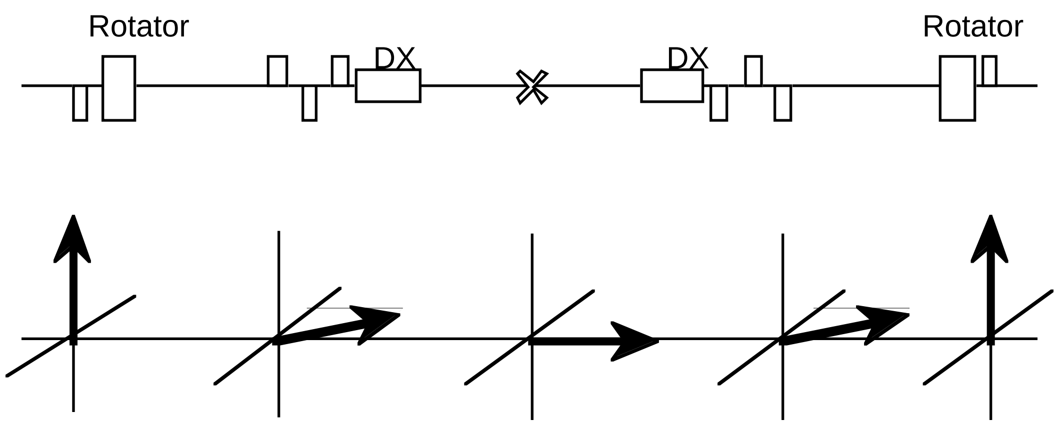
- Works for 250 GeV Protons with reasonable field strengths
- Large aperture, for necessary orbit distortions, ...

  ... yet high field to keep orbit distortions small and local
- Low current (low heat-leak through power leads) and tunable
- Fits in available space in RHIC ring
- Minimize number of different components to be built

Nice solution for Snakes and Rotators proposed by Ptitsin and Shatunov (BINP), and refined at BNL over past few years, using helical dipole magnets...

- high field superconducting helical dipole magnets keep orbit distortions small and allow for the spin manipulations to be performed in a compact region
- four helical dipoles fit within standard RHIC straight section, keeping the assembly between already cold superconducting quadrupoles Q7 and Q8
- Rotators located in “warm” regions (which must be modified slightly), but modular design allows Snake and Rotator hardware to be as similar as possible
- low current, many-turn magnet designs being considered

“D0” and “Dx” magnets are located between the Spin Rotators and the Interaction Point and bend the beam through an angle of θ = 3.7 mrad. Thus, the Rotators must place the spin vector into the horizontal plane, at an angle of $G\gamma\theta$ to the longitudinal direction. The settings for these magnets thus depend upon the proton energy.



Operating Scenario...

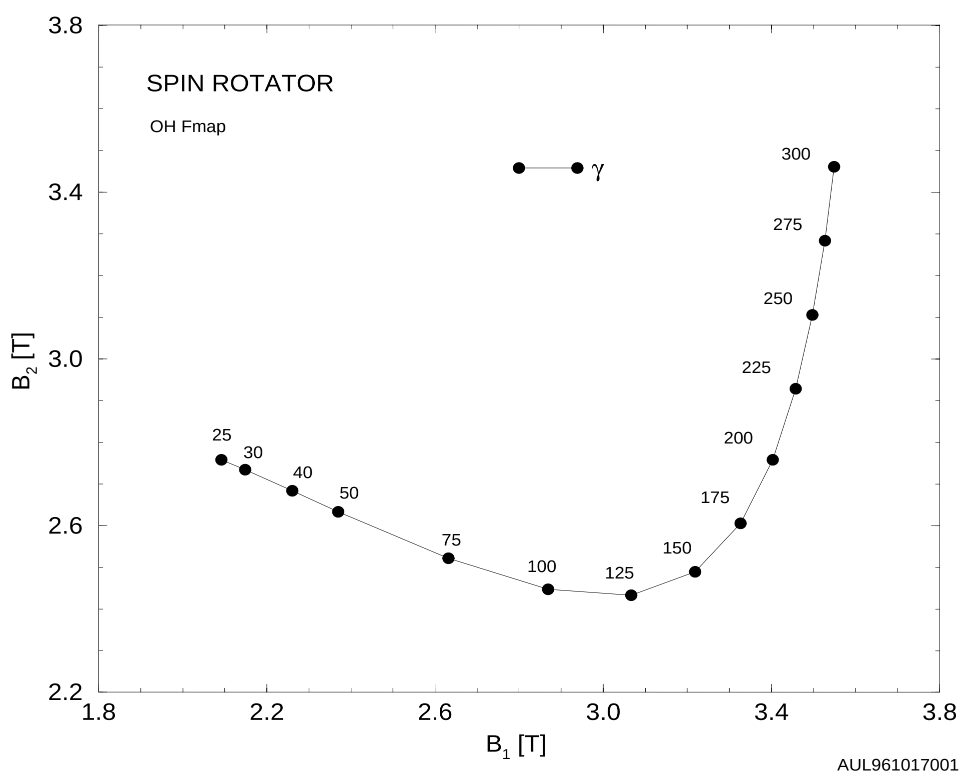
Siberian Snakes:

- On at injection through acceleration and storage
- Tuned for high energy

precession varies as $(1+G\gamma)/B\rho$ $G=1.793$

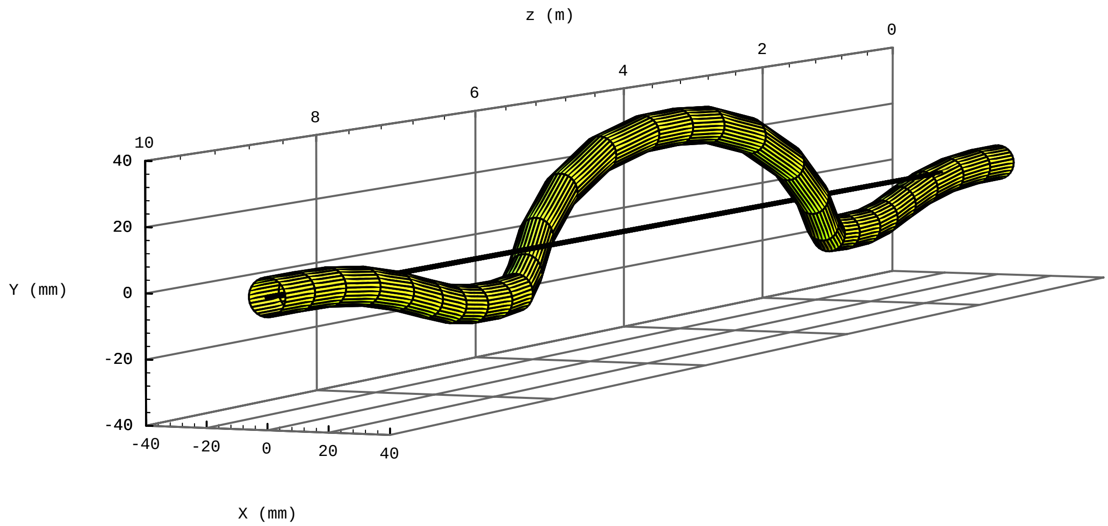
Spin Rotators:

- Off at injection and throughout acceleration
- Adiabatically turned on at flat top; likely before low-β squeeze
- Tune depends upon energy



Orbital Effects...

Ideal trajectory through the Snakes and Spin Rotators are not centered within the helical dipole magnets...



Intrinsic non-linear spiraling fields of the helix creates longitudinal fields as well as feed-down errors. Worry most about Snakes, as Rotators are on only at high field; orbit effects vary as $1/B\rho$

- Linear coupling

  2 Snakes generate coupling with $\Delta\nu_{min} \approx 0.003$

- Tune shifts

  2 "ideal" Snakes generate tune shifts of $\Delta\nu \approx 0.01$ due to the non-linear nature of the field. However, Snakes are on DC so is easily corrected

TOTAL FIELD ROTATION ANGLE in HELICAL DIPOLE MAGNETS

How to define “rotation angle” in a magnet with “real” ends...

We want integrated field components (B_x and B_y) to be zero along the axis of the magnet, indicating a rotation angle of 360^o.

Preliminary requirements stated $360^o \pm 0.1^o$

- Based upon closed orbit distortions generated, primarily, by the Spin Rotators (which begin and end with horizontal field directions).
- Also assumed no orbit correction necessary.

By noting that the Spin Rotators will only be energized (adiabatically) at full energy, and by noting that local closed orbit compensation of the Snakes can be straight-forwardly performed, the requirement was relaxed to **$360^o \pm 2.0^o$** (rms, over all Snake helical dipole magnets).

The present end design, with appropriate choice of the rotation angle of the “body field,” can accomplish this goal.

- 3-D modeling, and comparison with prototype (Okamura)
- Analysis of prototype magnet data (Okamura, Jain)

Roadmap Toward First Polarized Proton Run

Goal: First polarized proton physics run in YEAR TWO (Oct. 2000 --->)

- 100 GeV on 100 GeV
- Longitudinal polarization at STAR and PHENIX

Need: Polarized proton commissioning during YEAR ONE (Oct. 1999 --->)

- one ring, two Snakes, one polarimeter; energies up to 100 GeV

A 4-week commissioning plan proposal for YEAR ONE (Oct. 1999 --->):

- Transfer of polarized beam from the AGS and injection into RHIC. Commission filling of RHIC with bunches of alternate polarization sign. (6 days)
- Commissioning of the polarimeter at 25 GeV. Check for systematic errors. (7 days)
- Measurement of beam polarization in RHIC at 25 GeV with and without Snakes.(4 days)
- Accelerate polarized beam to 40, 60, 80, and 100 GeV. Commission polarimeter and measure polarization at each energy. (11 Days)

Schedule calls for:

1. Two Siberian Snakes available for one RHIC ring by Summer 1999.
2. One polarimeter available for one (same!) RHIC ring by Summer 1999 -- operating range 25 GeV to 100 GeV.
3. Remaining components (2 Snakes, 8 rotators, 2nd polarimeter system) installed by Summer 2000.

Present Project Status:

Accelerator Physics:

- Spin tracking studies concentrating on closed orbit correction schemes, crossing of strongest intrinsic resonances.

Magnets:

- Magnet R&D: success with both methods in making 4 Tesla helical dipole magnets! Slotted magnet more robust, chosen as design. >80% of Mechanical/Electrical drawings complete; most of remaining work is in cryostat assembly.
- Tooling (winding machine) is complete; most operational issues have been worked out. (Will still be learning things as we build first magnet.) Lamination stacking fixture complete.
- Procurement of long-lead-time items (aluminum tubes, iron yoke laminations, superconductor) in good shape.
- First full-length production magnet was to begin in January; delays, primarily in tube machining. First full-length tube now mounted on winding machine and winding has begun.

Polarimeter:

- Toroid double-arm polarimeters are too expensive for our “actual” budget. Building scaled-down, “day one” system.
- Developing CNI system as second “day one” polarimeter, and considering future systems such as jets.